Team Reports: University of Hawaii, Manoa

University of Hawaii, Manoa
Executive Summary
Principal Investigator: Karen Meech

Water is the medium in which the chemistry of all life on Earth takes place. Water is the habitat in which life first emerged and in which all of it still thrives. Water has modified Earth's geology and climate to a degree that has allowed life to persist to the present epoch. We propose to create a research and education framework that links the biological, chemical, geological, and astronomical sciences to better understand the origin, history, distribution, and role of water as it relates to life in the universe. We focus on scenarios involving the sources and distribution of water in planetary systems and the delivery and incorporation of water into rocky planets that orbit within the “habitable zones” of their parent stars. Our framework will include and connect research on major aspects of planetary water—in effect we aim to understand the terms of a “watery Drake equation” (Figure 1). Sub–themes of our research include the following:

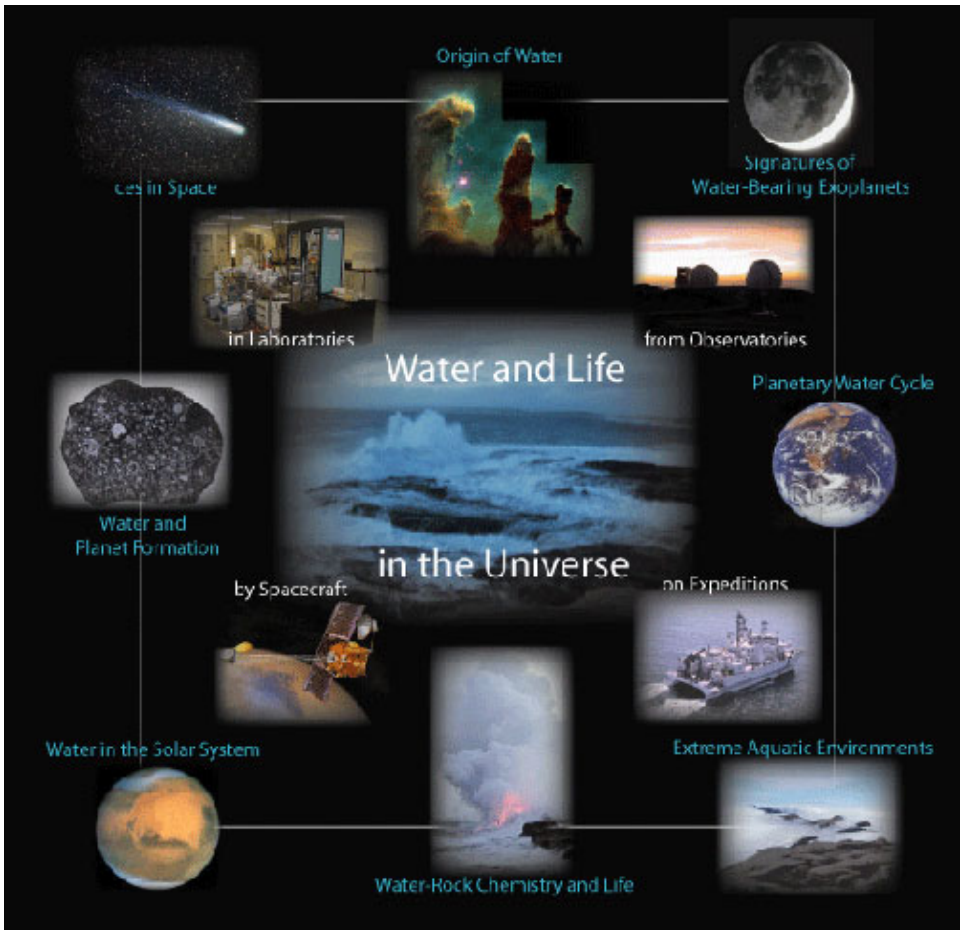

Figure 1. The Watery Drake Equation.

• Water is formed in the interstellar medium and in the denser molecular clouds that give rise to star–forming regions. Differences in elemental abundance, gas–phase chemistry, and grain chemistry will result in measurable variation in the abundance of water in those regions. Our team will use the powerful new sub–millimeter and infrared facilities on Mauna Kea to quantify the presence of water ice in the interstellar clouds, and to characterize and understand the environments where water exists in space (such as circumstellar disks).

• Comet ices preserve a chemical record of this precursor interstellar material, and detailed remote measurements of the isotopes of hydrogen in these icy bodies has shown that comets contributed some, but not all of the water to the Earth's oceans. Comets are also rich in the organic materials that are essential for life on Earth. Team members will investigate the inventory of both organics and ices in these small outer solar system denizens, specifically the comets, Centaurs, and Kuiper Belt objects.

• Because of the high abundance of water ice in the interstellar medium, water has played a vital role in physical and chemical processes that have lead to the formation of astrobiologically important molecules. University of Hawaii (UH) NAI team members will perform cutting–edge laboratory chemistry experiments to address, for the very first time, the important questions of how the basic life ingredients can be formed abiotically in extraterrestrial environments such as

molecular clouds, and the crucial role that water has played in their formation, and to understand the physical processes, as well as understanding the physics of complex molecule trapping, and formation on interstellar water–rich grain mantles and planetary ices.

• UH NAI team members will also use lab equipment to study the minerals in meteorites that formed as a result of interaction with liquid water early in the solar system. These minerals preserve a record of aqueous activity in their parent bodies that provides information about the abundance and distribution of water in the primordial solar nebula.

• The meteorites record the incorporation of water into silicate material in the primordial Solar System as an early step in its eventual inclusion in larger bodies, including planets. The cosmochemical record in meteorites shows that a large range of water abundance existed in the early Solar System, perhaps as a result of removal of water from the warm interior of the primordial nebula.

• Mars is the planet most resembling Earth; it contains unambiguous evidence for the activity of past and present water, and is probably the most likely to host or have hosted extant or extinct life. Studies of the history and action of water on Mars are thus of great importance in this regard. Our studies will model the hydrothermal and low–temperature alteration of crustal minerals and rocks by water, and team members will combine this with data from Earth observations and recent Mars missions to assess the Mars water inventory and its habitability.

• Water has been involved in life since its first appearance on the early Earth. The leading theories of the origin of life invoke prebiotic chemistry in low–temperature aqueous solutions, supplied with prebiotic molecules by atmospheric chemistry, or in the hydrothermal brines produced by high–temperature water–rock interactions. The first three billion years of the drama of life on this planet was played out entirely in aquatic environments. Water is also involved in geochemical reactions that maintain surface conditions permissive of life. The presence of water significantly alters the properties of minerals in Earth's crust and mantle, something crucial to the operation of plate tectonics. These geologic processes, in turn, drive many of the biogeochemical cycles important to Earth's habitability. Our team will investigate the water–rock chemistry in the deep oceans and its relation to habitats for life. The reaction between silicate rocks and water, particularly at high temperature (e.g., at submarine hot springs near mid–ocean ridges), produces aqueous fluids and altered mineral surfaces whose thermodynamic disequilibria are potential energy sources for life.

• Besides water, life also requires a source of carbon and nutrients, and an environment that is conducive to the propagation of genetic information. Many aquatic environments on Earth are challenging or “extreme” from the point of view of these other requirements. By studying these we can better understand what may limit the origin and persistence of life in aquatic habitats elsewhere in the universe. These extreme environments include lava–water interfaces in the Hawaii Volcanoes park as the magma from Kilaeua flows into the ocean, as well as steam geysers, high altitude lakes (such as lake Waiau on Mauna Kea),

and field work in volcanically active Iceland. We will focus here on a comparative study of microbial biodiversity and metabolic activity in these extreme aquatic habitats.

• We will develop an integrated model of planetary water and its early history on Earth–like planets, which can be used to explore the time–evolution of water on the early Earth, as well as Earth–size planets whose space environment or composition differ from Earth's. Extraterrestrial aquatic environments may be far more extreme than most encountered on Earth. Water inventories and cycles in Earth–sized planets around other stars may be quite different from our own. Planetary water abundance may be a very sensitive function of the chemistry in the planet–forming nebula, the water abundance in that nebula, the presence of giant planets and factors such as ultraviolet radiation from the central star.

• Finally, we will develop concepts and prototype hardware for instruments that could be used to detect and characterize life on other planetary bodies.

• By developing and testing models, and exploring the outcomes of alternative scenarios, we seek to determine what controls the abundance and distribution of water and hypothetical aqueous habitats in other planetary systems. This research will directly support the NASA search for past or present life on Mars and efforts (such as the NASA Terrestrial Planet Finder) to directly detect and characterize Earth–sized exoplanets.

Accomplishments

We are halfway through our first year, and most of our work can be characterized as getting set up. Nevertheless, we do have some initial science accomplishments.

Infrastructure set up

• The proposed framework of our research will support a group of postdoctoral scholars who will carry out independent, interdisciplinary research spanning two or more of the investigators' (or affiliated investigators') research specialties. Considerable effort was made this year in the recruitment of eight postdoctoral fellows; two additional fellows will be recruited next year. The postdocs arrived between June and October, and the others will arrive over the summer.

• We have negotiated with the University and acquired ~1800 sq. ft. of centrally located campus space for our postdoctoral “Water Hole” (office area and meeting facilities). Major renovations on the room are complete, and the procurement has begun for carpeting, furniture, and computer equipment.

• We have established an NAI Visiting Faculty Scholars Program, including acquiring and furnishing a visiting faculty apartment within walking distance of the University of Hawaii Campus . As part of the program we have established an NAI Visiting Faculty Scholar Committee and guidelines for its operation, and have received our first visitor under this program, Akiva Bar–Nun from the Tel

Aviv University ; he is actively working with several of our team members.

• We commissioned and calibrated a novel ultra high vacuum surface scattering machine in the chemistry department to investigate the formation of astrobiologically important molecules in the interstellar medium and in our solar system.

• Leveraged against the UH NAI grant, we have obtained NASA and DOD funding that use UH−NAI grant personnel to design, construct, and test a prototype laboratory miniature instrument for direct mass spectral analysis of liquids. We have built an initial laboratory prototype and demonstrated ionization at low vacuum (~3 Torr).

• We have also obtained National Science Foundation (NSF) funding that leverage UH−NAI grant personnel to design, construct, and test a prototype instrument for contamination−free sampling of basement rock fluids from deep−sea boreholes.

Science Results

- Cryogenic experiments, in collaboration with colleagues in Israel, with amorphous gas−laden water ice samples show that pre−perihelion activity in comets at large distances may be explained by the annealing (re−organization of the crystal structure) of the water ice which allows the trapped gases to escape.
- We have conducted experiments using the newly commissioned UH ultra high vacuum surface scattering machine, on the formation of two C_2H_4O isomers and nitrous oxide in interstellar ices, and have 3 papers in progress.
- The discovery and subsequent follow up of a discovery of a major accretion event and flare up in a young circumstellar disk has lead to the development of a new model for the onset of these events. This has important implications for short−lived heating events in early solar systems that might contribute to chondrule formation and aqueous alteration of early solar system material.
- Inorganic generation of hydrogen gas during hydration of mantle rock may fuel microbial life on other planets, as it does on Earth. This process has been demonstrated in serpentinite mud volcanoes in the Mariana forearc, on the floor of the Western Pacific Ocean, where it supports a community of Archaea.

New Collaborations and Initiatives

• Co−I Binsted has established a collaboration with NAI Ames member C. McKay, and they have submitted a major NASA equipment proposal to develop an innovative new sensor network andto deploy it in the arctic for hydrology research.

Mission Involvement

• UH NAI Principal Investigator K. Meech is a co−Investigator on NASA's Deep Impact mission. In addition to coordinating science observations of the comet target, 9P/Temple 1 with the goals of our comet/water investigations, we are planning a large UH−NAI lead outreach effort at the time of the mission. This will include teacher workshops leading up to the date of Encounter (July 4, 2005) and observing with the Faulkes Telescope facility on Maui . Two new graduate students have joined the UH NAI group to work on Deep Impact and Astrobiology−related projects.

• Co−I Toby Owen is heavily involved with the Cassini Saturn mission.

Education/Public Outreach Activities

K−12 Programs :

• Alii Summer Teacher Workshop – The first Astrobiology Laboratory Institute for Instructors was held June 14−18, 2004 . This was a collaboration with 2 NAI teams, SETI and Indiana−Princeton−Tennessee Astrobiology Initiative (IPTAI). Over 50% of the UH NAI team scientists contributed lectures, laboratory tours, and hands on activites to this program.

• Deep Impact and the Faulkes Telescope Facility – Development of a teacher−training program to utilize the 2−m Faulkes telescope on the summit of Haleakala, Maui , is underway. Workshops for Spring, 2005, are planned to prepare teachers so that they can utilize this resource (a research−grade telescope dedicated to outreach) to contribute to the Deep Impact mission encounter during July, 2005. This will also be the initiation of a more in−depth Faulkes teacher−training program. This telescope will be available for general use in October, 2004.

• Student Programs – Ten Hawaiian teachers and two from the mainland, trained in 2003, spent the fall, 2003, and spring, 2004, mentoring 59 students for astrobiology research projects. Of these students, 50% entered their projects in school science fairs, and 17% were recommended for State Fair (three projects receiving awards). One project was recommended for the Intel International Fair.

Public Outreach

• Hawaii Volcanoes Park – We are beginning a collaboration with the NASA Ames NAI EPO team, which has fostered a partnership with Yellowstone National Park . We intend to replicate this activity in the Hawaii Volcanoes National Park . Contact has been made with park staff, and plans are underway to collaborate with a PI at the Berkeley Space Sciences Lab to get an EPO grant from NASA for this project.

• Astrobiology Traveling Exhibit – We are collaborating with the NAI Carnegie team for loan of this traveling exhibit. This will be displayed from January−April, 2005, on all islands, with Aloha Airlines donating inter−island freight. We will plan science activities and lectures with our team members on each island.

Graduate Programs

• Astrobiology Winter School – We are collaborating with the University of Arizona (UAZ) NAI team to offer an Astrobiology Winter School for approximately 40 graduate students annually each January. The school will be offered in alternate years in Hawaii and Tucson . Both UH and UAZ are developing “boards” to plan the winter school content each year, and we will exchange two scientists to be on each other's boards. The first Winter school will be held for two weeks in Hawaii during January, 2005, with the theme of “Water in Space and on Earth.” The instructors will be UH NAI team scientists and collaborators.

• Astrobiology Seminar Series – We have set up an astrobiology seminar series, a one−credit seminar for UH graduate students and advanced undergraduates, to be offered in the Fall, 2004. All UH NAI team co−Is and postdocs will be participating.

Other Collaborative Efforts

• Star and Planet Formation Day – UH NAI Co−I B. Reipurth organized a scientific symposium at the Institute for Astronomy as part of our NAI activities on February 26, 2004 . Many of the local NAI team members and collaborators participated. The program is included in the table below.

09:30	Colin Aspin	Near−IR Spectroscopy of Herbig−Haro Energy Sources
09:50	Tracy Beck	Variations in Obscuration toward T Tau South
10:10	Crystal Brogan	W51B/W51C: Shock Triggered Star Formation?
10:30	Chris Davis	Near−infrared IFU Spectroscopy of Star Forming Regions at UKIRT
10:50	Eric Gaidos	Age−dating of Stars and Planetary Systems using Giant Planets
11:10		Coffee Break
11:30	Masa Hayashi	Subaru Disk and Planet Searches
11:50	George Herbig	NGC 1579 and LkHa−101
12:10	Klaus Hodapp	The Earliest Stages of Star Formation in NGC 1333
12:30	Martin Houde	The Orientation of the Magnetic Field in Molecular Clouds
12:50	Robert Jedicke	Space Weathering on Asteroids
13:10		Lunch
14:00	David Jewitt	CO in Cometary Precursors
14:20	Ralf Kaiser	Formation of Astrobiologically Important Molecules in Extraterrestrial Ices
14:40	Michael Liu	Brown Dwarf Disks in the Mid−Infrared
15:00	Karen Meech	The Deep Impact Mission
15:20	Gerald Moriarty−Schieven	A Complete Survey of Star Formation in L1551
15:40		Coffee Break

16:00	Tae−Soo Pyo	Spectroscopic Study of [FeII] Outflows with High Angular Resolution
16:20	Bo Reipurth	Companions to FU Orionis Objects
16:40	Ed Scott	Dust in the Protosolar Disk: Clues from Matrices of Primitive Meteorites
17:00	Alan Tokunaga	Infrared Spectroscopy and Imaging of KH15D
17:20	Jonathan Williams	SMA Observations of the Orion Proplyds

- The 2004 Bioastronomy Meeting – UH NAI Team members and collaborators have played a major role in the set up of the Bioastronomy 2004 meeting. UH NAI lead, Meech, is President of Commission 51 (Bioastronomy) of the International Astronomical Union, and it was her proposal that the meeting be held in Iceland. UH NAI Collaborator Thorsteinn Thorsteinsson was contacted and agreed to chair the local organizing committee with Meech as one of the members. UH NAI members Meech, Gaidos, and collaborators Ehrenfreund and Thorsteinsson are on the Science organizing committee. Meech has done all the fund−raising for the meeting, including securing NAI sponsorship.
- The development of two 16−inch telescopes, one for Hawaii and one for Cerro Tololo Observatory in Chile, has begun in order to do all−sky monitoring of star forming regions to create temporal catalogs of the variability of young stars.
- We have undertaken a collaboration with Lowell Observatory colleagues in order to gain access to some telescope time for our UH NAI research and outreach programs. To this end we have been developing an intelligent scheduler for automated scheduling of the telescope driven by requests. The Lowell 31−inch telescope observing database has been upgraded. An interface to interact with the database has been created, and an intelligent scheduler developed and nearly fully debugged. Anticipated completion is expected during summer, 2004. The complete system will be used for scheduling astronomical observations, both for research and outreach.